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TIRE PRESSURE MONITORING SYSTEM

(57) Abstract

A tire pressure monitoring system or a monitoring system for a first parameter has a sensor (14, 200, 356) and a receiver (20, 90, 220, 370). The sensor (14, 200, 356) is located at a first location end detects the tire pressure or a first parameter. The receiver 20, 90, 220, 370) is located at a second location close to the sensor (14, 200, 356) and generates a signal indicating the first parameter or the tire pressure. It has a first coil (62, 230, 347), a second coil (64, 232, 376) and an amplifier (70, 94, 272) with a feedback branch. The two coils are oriented with respect to each other in such a way that they are electromagnetically coupled with each other and the feedback in the feedback branch of the amplifier (70, 94, 372) is zero or negative. The measured first parameter or tire pressure can be displayed by a display unit (80). The sensor has preferably an oscillator (32, 362) with a coil (34, 202, 364) and a capacitor (36, 204, 366), where either the inductance or the capacitance can be pressure-dependent. Alternatively, a pressure capsule can be used to open or close a switch in the oscillator (36, 362) as a function of pressure. When the sensor (14, 200, 356) is in working distance of the receiver (20, 90, 220, 370), the oscillation state of the receiver changes from a non-oscillating rest state to an active oscillating state as a result of the electromagnetic coupling between the sensor (14, 200, 356) and . . .

Specification

The present invention pertains to monitoring systems, especially to systems for monitoring the pressure in the tires of motor vehicles and for generating signals which indicate that pressure.

Correct tire pressure is very important for the safety and comfort of motor vehicle operation. A pressure which is too high increases tire wear and impairs the handling of the vehicle. A pressure which is too low also leads to increased tire wear and impairs handling but also detracts from the roadability of the vehicle.

The conventional method of checking the pressure of the air in tires – referred to in the following as "tire pressure" – is to use a mechanical pressure gauge, which is pushed onto the tire valve. Devices such as these can provide accurate measurement of tire pressure, but they are not suitable for the continuous monitoring of tire pressures. For example, when the driver wishes to check the tire pressure, he or she must stop the vehicle first and climb out before taking a measurement. Mechanical tire pressure gauges of this type therefore cannot keep continuous track of the tire pressure and warn the driver as soon as the pressure in a certain tire has reached a value which is hazardous under normal driving conditions (for example, less than 14 p.s.i. for a conventional vehicle).

Systems with an active capacitor/coil oscillator (LC circuit) are known, which are attached to the tire to monitor the tire pressure. An active LC circuit of this type, however, requires an energy source. Because it is attached to the tire, the energy source and additional circuit elements are subjected to vibrations because of the rotation of the tire and to other harsh conditions such as temperature changes. Because of their installation in the tire, the circuit elements are also difficult to install and difficult to replace if they are damaged. Finally, systems of this type are not usually able to transmit a warning to the driver when the tire pressure falls below a predetermined threshold or exceeds a predetermined maximum threshold.

The goal of the present invention is to create a tire pressure monitoring system which eliminates these disadvantages. A tire monitoring system of this type offers the advantage that the tire pressure can be monitored continuously by means of passive sensors. In addition, the sensors can be more easily attached to the tire; the system is less susceptible to malfunction; and the changes in tire pressure can be monitored with precision. The sensors, which operate on the basis of tire pressure-dependent changes in electric capacitance or inductance, can be designed either to display the tire pressure only when it leaves a predetermined range or to display the current tire pressure at all times.

This goal and these advantages are achieved by an invention according to the attached claims.

The present invention creates a tire pressure monitoring system based on the use of passive LC circuits, which are installed in the tires. These passive circuits require no energy supply and are therefore both cheaper and longer-lasting than the active tire pressure sensors of known monitoring systems. The tire pressure monitoring system gives the driver preferably either an audible alarm or an optical signal when the tire pressure in a tire falls below a threshold value. The tire pressure monitoring system can also be designed in such a way that it supplies the driver with a continuous digital readout of the tire pressures currently being measured in all tires. The sensing is carried out by a sensor with variable capacitance or by a sensor with variable inductance.

In a concrete embodiment, especially one according to Claim 1 in conjunction with Claim 6, the tire pressure monitoring system is provided with a sensor on at least one of the tires of the vehicle, with a receiver, and with a tire pressure display. The sensor is in a fixed position relative to the tire and senses the tire pressure in it. The receiver is in a fixed position relative to the vehicle and is located at a point outside the tire but near the sensor. It generates a signal, which indicates the tire pressure detected by the sensor. The receiver has a first coil, a second coil, and an amplifier with a feedback branch, the two coils being oriented with respect to each other in such a way that they are coupled electromagnetically with each other and so that the feedback in the resting state, that is, the state in which the sensor is out of range, is

either essentially zero or negative. The tire pressure display device is connected to the receiver and displays the tire pressure status on the basis of the signal obtained from the receiver.

In another preferred embodiment, especially one according to Claim 7 in conjunction with Claim 12, a monitoring system for a first parameter has a sensor, a receiver, and a display device. The sensor detects the first parameter. The receiver has a first coil, a second coil, and an amplifier with a feedback branch. The first and second coils are oriented with respect to each other in such a way that they are electromagnetically coupled and so that the feedback in the resting state is either essentially zero or negative. The display device shows the user the value of the first parameter.

In another preferred embodiment, especially one according to Claim 13 in conjunction with Claim 19, a tire pressure monitoring system consists of a sensor, a receiver, and a tire pressure display device. The sensor is installed in a first housing and in a second housing, both of which are attached to the rim and are electrically connected to each other. The receiver is located outside the tire and close to the measuring sensor and can be coupled electrically [Sic; electromagnetically? – JPD] with the sensor, so that a signal indicating the pressure detected by the measuring sensor can be generated. This signal is displayed by the tire pressure display device.

In another embodiment, especially one according to Claim 20 in conjunction with Claim 26, a monitoring system for a first parameter is provided, which has a sensor and a receiver. The sensor has a coil with an inductance L, the coil being oriented with respect to a ferrite core. This core changes the inductance L of the coil, as a result of which the measuring sensor is able to sense the first parameter. The receiver is close to the sensor, can be coupled electromagnetically with it, and generates a signal, which indicates the first parameter sensed by the measuring sensor.

In another embodiment, especially one according to Claim 27 in conjunction with Claim 32, a monitoring system for a first parameter is provided with a sensor and a receiver. The sensor detects this first parameter. The receiver is located near the sensor and has an

amplifier with a feedback branch. The amplifier is in a non-oscillating rest state when the sensor is not electromagnetically coupled with the receiver. It is in an active, oscillating state when the sensor is electromagnetically coupled with the receiver.

In another embodiment, especially one according to Claim 32 in conjunction with Claim 39, a sensor for monitoring a first parameter is provided with a capacitor, a coil, and a ferrite core. The ferrite core is oriented with respect to the coil, which has an inductance L. When the ferrite core moves with respect to the coil, the inductance L changes as a function of the first parameter.

In another embodiment, especially one according to Claim 40 in conjunction with Claim 45, a receiver for monitoring a first parameter by means of a sensor is provided. The receiver has an amplifier, which has a first coil and a second coil. The amplifier, to which the first and second coils are connected, has a feedback branch. It is in a non-oscillating rest state when the sensor is not electromagnetically coupled with the receiver. When the sensor is electromagnetically coupled with the receiver, the amplifier is an active, oscillating state.

The present invention creates a tire pressure monitoring system. Of course, with a sensor which is installed in a first location and a receiver which is installed at a second location, the present invention can monitor any desired variable. The invention is thus not limited to the monitoring of tire pressures. Embodiments of the present invention can be used to measure pressure, temperature, movement, load, strain, etc., and the sensors can be attached on or in various objects such as tires, conveyor chains, or even the human body. Thus the sensors can be used in combination with the receivers to detect not only tire pressure but also other parameters such as temperature and other physical variables of moving or rotating objects. As a result, the previously mentioned disadvantages of the currently available methods and techniques for monitoring tire pressure or other variables are either eliminated or reduced in their severity.

The invention is explained in greater detail below on the basis of the drawing:

– Figure 1 shows a schematic diagram, from above, of the drive train of a motor vehicle with a tire pressure monitoring system;

– Figure 2 shows a circuit diagram of a first embodiment of a sensor;

– Figure 3a shows a partially cut-away view, in perspective, of a pressure capsule of a type which can be used in the circuit of Figure 2;

– Figure 3b shows a cross-sectional view of a second embodiment of a pressure capsule which can be used in Figure 2;

– Figure 4 shows a simple circuit diagram of a first embodiment of a receiver;

– Figure 5 shows a circuit diagram of the electromagnetic fields generated by the coils of Figure 4;

– Figure 6 shows a schematic diagram of an arrangement of the two coils of Figure 4;

– Figure 7 shows a simplified schematic diagram of the way in which the sensor of Figure 2 operates together with the receiver of Figure 4 when the sensor arrives in a position near the receiver;

– Figure 8 shows a circuit diagram of the receiver of Figure 1 and of the sensor of Figure 2;

– Figures 9A and 9B show time series of the voltages obtained from the operational amplifier and detector of Figure 8;

– Figure 10 shows a simplified circuit diagram of an LED driver of a type which can be used in the system according to Figure 1;

– Figures 11A and 11B show other embodiments of a sensor with a pressure-sensitive capacitor;

– Figure 12A shows a simplified circuit diagram of a second embodiment of a receiver;

– Figure 12B shows a schematic diagram of the time series of the voltages obtained from the receiver of Figure 12A;

– Figure 13 shows a diagram of the oscillation period of the output signal of the receiver of Figure 12A as a function of tire pressure at constant inductance of the receiver;

– Figure 14 shows a simplified schematic diagram of the measuring and display capabilities of the system according to the second embodiment;

– Figure 15 shows a block circuit diagram of the converter block of Figure 14;

– Figure 16 shows time series of voltages measured at different nodes of the circuit of Figure 15;

– Figure 17 shows a plot of the pressure values stored in the memory of the processor used in the second embodiment;

– Figure 18 shows a perspective view of the sensor of Figure 2 attached to a wheel rim by means of a first fastening technique;

– Figure 19 shows a diagram similar to Figure 18 with a second fastening technique;

– Figure 20 shows a cross-sectional view of the sensor of Figure 2, fastened to the rim by a third fastening technique;

– Figure 21 shows a cross-sectional view of the part of the sensor which is attached to the rim in Figures 18-20;

– Figure 22 shows a pressure monitoring system according to a third embodiment;

– Figure 23 shows a schematic diagram of the way in which the sensor and the receiver of Figure 22 interact after the sensor has is rotated into a position close to the receiver;

– Figure 24 shows a schematic diagram of a second arrangement of the two coils of Figure 23;

– Figures 25A and 25B show schematic diagrams of two conductor loops L1 and L2 to illustrate the currents flowing in the same or opposite directions in Figure 23;

– Figure 26 shows a sequence diagram of the interaction between the sensor and the receiver of Figure 23;

– Figures 27A and 27B show a first embodiment of the sensor of Figure 23;

– Figures 28A and 28B show a second embodiment of the sensor of Figure 23;

– Figure 29 shows a simplified circuit diagram of the receiver of Figure 22 together with the measurement and readout wiring according to the third embodiment; and

– Figure 30 shows time series of voltages measured at various nodes of the circuit of Figure 29.

Three different embodiments of a tire pressure monitoring system are described below.

Figure 1 shows a tire pressure monitoring system 10, mounted on the drive train 12 of a motor vehicle. The tire pressure monitoring system 10 has four sensors 14a-14d, each of which is mounted on either the inside or the outside of a wheel 16a-16d. Four receivers 20a-20d are attached by straps (not shown) to the drive train 12 a few centimeters from the inside

flank of the assigned wheel. While the vehicle is being driven, the tire pressure monitoring system is able to monitor the tire pressure in each tire16a-16d on the basis of the electromagnetic coupling which is present between the sensors 14a-14d and the receivers 20a-20d when the rotation of the tires 16a-16d brings the sensors 14a-14d into working distance of their associated receivers 20a-20d. As a result of this coupling, the point at which the tire pressure falls below a predetermined threshold value can be determined and an appropriate warning can be transmitted. Alternatively, the driver can be provided continuously with data on the current tire pressures. In the following, three different embodiments of the tire pressure monitoring system 10 are explained.

1st Embodiment

Figure 2 shows the design common to all of the sensors 14a-d shown in Figure 1; in the following, only the sensor 14a will be described, since it is a representative of them all. Sensors 14b-d are identical to it in design and function. The sensor 14a is preferably attached to the inner rim flange 30 of the wheel 16a [Sic → to the inside surface of the flank 30 of the tire – JPD] or to the rim of the wheel 16a. It has an LC circuit 32 with a coil 34 and a capacitor 36. It also has a switching element 38 with a closed membrane or pressure capsule 40, which opens or closes a switch 42. The circuit 42 [Sic → 32? – JPD] is passive; that is, it requires no input of energy. The coil 34 and the capacitor 36 form an oscillating circuit (LC circuit), which is either conductive or non-conductive, depending on the pressure in the tire to which it is assigned. The pressure capsule 40 thus controls the conductivity of the circuit 32 as a function of the tire pressure.

The coil 34 shown in Figure 2 consists preferably of several turns of wire, e.g., a helical piece of wire with a thickness of 0.05 mm, which is wound around a diameter of, for example, 50-60 mm. The coil 34 together with the switching element 38 can be permanently attached to the flank 30 at a point inside the tire by vulcanization with liquid rubber . The switching element 38 closes the circuit as a function of pressure, and when the circuit is closed, it becomes conductive. The capacitor can be attached to the cover 44 (see Figures 3a and 3b) of the switching element 38. The leads of the coil 34 and of the capacitor 36 are both soldered to

the base 46 of the switching element 38. The circuit 32 can also be designed so that it is attached to the rim of the wheel 16a. This will be explained further below.

Figure 3a shows the design of the switching element 38 in greater detail. The pressure capsule 40 is completely enclosed by the cover 44 and the base 46 and forms a hermetically sealed unit. The pressure capsule 40 preferably consists of a thin metal membrane, which is welded to the base 46 so that an interior space is defined inside the membrane, which is hermetically sealed off from the outside pressure, i.e., from the environment. Several spacers 50 are attached to the base 46. The cover 44 is attached to the spacers 50 and extends over the top of the pressure capsule 40.

One end 54 of an electrically conductive spring 52 is attached inside the cover 44 [Sic; attached to the outside surface of the cover? (See Figure 3a). – JPD]. The unattached end 56 of the spring, which is bent over at an angle, establishes electrical contact with the surface of the membrane of the pressure capsule 40 as a function of the position of the membrane. The spring 52 consists preferably of a steel wire with a thickness of approximately 0.2 mm. It closes the switch of the switching element 38 when the tire pressure reaches a certain threshold value.

In one embodiment, the spring 52 closes a circuit in the switching element 38. A closing of the circuit in the switching element closes the LC circuit 32 and thus activates it. Thus the status of the switching element 38 depends on the tire pressure. If the tire pressure is at or near the normal operating pressure, such as 30 p.s.i., the membrane of the pressure capsule 40 is depressed, as a result of which the contact 42 is open. If the tire pressure falls far enough, however, such as to a pressure of less than 15 p.s.i., the membrane of the pressure capsule 40 rises, as a result of which the free end 56 of the spring makes contact with the membrane of the pressure capsule 40 and closes the contact point 42, as a result of which the LC circuit 32 is closed.

Figure 3b shows an alternative switching element 38'. It consists of the same components as the switching element 38 but also has a nonconductive housing 51, which

isolates the cover 44' and the base 46' from each other. Otherwise, the design and function are the same as those of switching element 38. The switching element can thus be designed in various ways.

The LC circuit 32 can be constructed out of thin metal foil, which forms an open ring. The coil 34 and the capacitor 36 can be formed out of this foil and thus provide an LC circuit with the necessary properties. The two ends of the ring are connected directly to the switching element 38. Designing the circuit in this way leads to low production costs with no loss of performance.

The design of a receiver 20a will now be described on the basis of Figures 2 [Sic → 1? – JPD], 4, and 5. The other receivers 20b and 20d are identical to it with respect to design and function. The receiver 20a is supplied with energy by the battery 60 of the vehicle. The receiver 20a has coils 62, 64 (see Figure 4), each of which has several windings 66, 68 (see Figure 5). The receiver 20a also has also an amplifier 70 (see Figure 4), which, together with the coils 62, 64, forms an oscillator, the properties of which depend on the orientation of the coils 62, 64 with respect to each other. Each loop 66 of the coil 62 interacts with an oppositely directed flux generated by the current passing through the other coil 46 [Sic → 64 – JPD], which is also supplied with current from the battery 60 (see Figure 5). Similarly, each loop 68 of the coil 64 interacts with the coil 62. Because they are connected to the amplifier 70 (see Figure 4), the coils 62, 64 can be adjusted in terms of their interaction so that they produce either positive, negative, or no feedback.

Because, as illustrated again in Figure 6, all of the feedback – whether positive, negative, or zero – depends on the orientation and design of the coils 62, 64, the desired feedback can be adjusted by selecting a suitable angle for the position of the coils with respect to each other upon installation of the coils on the drive train of the motor vehicle. The coils 62, 64 are attached to the drive train so that an angle α is formed between them. This is done with the help of a tuning mechanism 72, which is installed between the coils and the sensor. This tuning mechanism 72 is preferably a small piece of foil. The coils 62, 64 can thus be tuned by installing the foil a greater or lesser distance away from the coil 64 before the coils 62, 64 are

attached in their final positions. After the coils 62, 64 have been oriented and tuned, they are permanently fastened to the locations thus determined. The feedback of the circuit is preferably adjusted to zero or to a slightly negative value, so that the oscillations cannot build up by themselves, which would cause the amplifier 70 to function as a multivibrator.

The feedback status of the circuit changes whenever the sensor 14a moves to within working distance of the receiver 20a. This is shown in Figure 7a and will be described in greater detail further on.

As can be seen in Figure 1, each receiver 20a is connected either by suitable wiring or by wireless means to an LED display interface 80. This interface 80 is preferably located in the passenger compartment of the motor vehicle. It shows the driver the current status of each tire 16a-16d. The interface 80 can have four light-emitting diodes (LEDs) 83a-d, one for each tire. For a vehicle with more than four wheels, of course, the appropriate number of additional LEDs will be provided. They can be mounted suitably in the dashboard. They light up preferably only when the tire pressure of a tire has exceeded an allowable maximum value or fallen below an allowable minimum.

Figure 8 shows the circuit diagram of one of the amplifiers [Sic → receivers – JPD] 20 in greater detail, which is designated 90 here. The coil 62 and an input capacitor 92 form the input circuit, which is designed to amplify the sensitivity at the resonance frequency of the sensor 14a installed in the wheel. An operational amplifier 94 is used to amplify the signal, the amplification factor being adjusted by means of the resistors 96, 98. The amplifier 100 also amplifies the current, so that the total amplification of the receiver 90 is the sum of these two amplifications. Specifically, the output signal tapped at the collector of the transistor T2 is adjusted so that it is zero when the orientation of the coils L1 and L2 with respect to each other is such that they have no feedback. By shifting the positions of these coils L1 and L2 with respect to each other, either negative or positive feedback can be obtained. If the feedback is positive, a signal is present at the output of the receiver 90. If the feedback is negative, the output continues to be zero. This means that the output of the operational amplifier 94 is greater than "1" when the following state is present: $K\beta > 1$, where $K = K1 \cdot K2$. K1 stands

here for the amplification of the operational amplifier 94; K2 stands for the amplification of the transistor 100; and β stands for the coefficient of the coils 62, 64 with respect to each other. This variable β depends on the position of the coils 62, 64, on their windings, and on their size.

For the final tuning, adjustments are made at a constant $K\beta$ by changing the positions of the coils L1 and L2 with respect to each other until $K\beta < 1$.

A cascade amplifier 102, furthermore, formed by the transistor 103, functions as a pulse detector for the operational amplifier 94. The other components shown in Figure 8 are used to balance the direct voltages.

Figure 10 shows a simplified circuit diagram of a preferred LED interface 80. The interface 80 consists of four NAND logic gates 104a-d. The gates are driven by inputs 106a-d, which are connected to the outputs of the receiver 90 for the corresponding tires 16a-16d. The second inputs 108a-d are connected to a free-running oscillator 110. The oscillator 110 produces a square-wave oscillation with a frequency in the range between, for example, 0.33 and 0.5 Hz. If the tire pressure in each tire 16a-16d is close to the normal operating pressure, the inputs to the logical NAND gates 104a-d are a logical "0". As a result, the outputs of the buffered inverters 112a-d, which are connected to the outputs of the NAND gates 104a-d, are also logical "0". Then all of the LEDs 83a-d are turned on. The LED interface 80 can also give an acoustic warning signal by way of a counter 114 and a corresponding transistor 115. A second oscillator 116 serves as a pulse generator. Two inverters 117, 118 connect the oscillator 116 to an acoustic warning device such as a buzzer 119.

The way in which the tire pressure monitoring system of this first exemplary embodiment works will now be explained. The function of the tire pressure monitoring system is based in principle on the mutual interference which arises between two electromagnetic fields generated by the coils 62 and 64 of the receiver 90 and on the electromagnetic coupling with the LC circuit 32 of the sensor 14a-14d, which is mounted on the inside or on the outside of each tire 16a-16d. If, as a function of the tire pressure, the circuit 32 is closed and activated and moves to within working distance of the coils 62, 64 of the receiver 90, the receiver 90 will

oscillate at a frequency which depends on the natural frequency of the circuit 32. The sign of the feedback between the coils 62 and 64 thus changes from minus to plus. The shape and amplitude of the oscillation depend, of course, on the degree of feedback, on the design of the coils, and on the amplification by the amplifier 70 (see Figure 4).

If the circuit 32 is open, that is, nonconducting, no oscillation occurs when the rotation of the tire carries it to within working distance of the receiver 90. If the circuit 32 is closed, however, the operational amplifier 70 generates an oscillating output voltage when the coils 34, 62, 64 are aligned with each other. The frequency of this oscillating voltage corresponds to the natural frequency of the circuit 32. The output voltage of the operational amplifier 70 is shown as a time series 120 in Figure 9A. The output voltage of the receiver 90 is shown as a time series 122 in Figure 9B.

If, for example, the tire pressure in tire 16a falls below a lower limit, as a result of which the switching element 38 is closed, a logical "1" is generated by the receiver 90 and transmitted to the input 106a of the NAND gate 104 [Sic → 104a – JPD] (see Figure 10). As a result of this logical "1", the LED 83a will blink at the frequency of the oscillator circuit 110.

The second oscillator circuit 116 comes into play when a logical "1" is present at the input 106a. The oscillator circuit 116 then generates pulses at an audible frequency. These are sent via the two inverters 117, 118 to the circuit output, as a result of which an audible warning signal is produced by, for example, the buzzer 119.

The simultaneous blinking of LED 83a and the buzzing of the buzzer 119 has the effect of activating the counter 114, which counts the pulses coming from the oscillator 116. The counter 116 counts 2n – 1 pulses, and then, upon the 2n-th pulse, its output becomes a logical "1". This is sent to a transistor 115, which thereupon becomes conductive and short-circuits the output of the inverter 118, as a result of which the audible alarm signal of the buzzer 119 is turned off. The 2n output is also sent to the EN input of the counter 114, so that the counter stops counting. From this point on, the driver is warned only by the continuous blinking of LED 83a, which informs him that the tire pressure of tire 16a is too low. This combination of

acoustic and optical warning signals is activated again whenever the internal combustion engine is started, the acoustic alarm being turned off by the counter 114 after a predetermined length of time, as explained above.

2nd Embodiment

Figures 11 and 14 show a second embodiment, which provides continuous monitoring of the tire pressure of the tires of a motor vehicle. A very accurate digital output of the current tire pressure of each tire is produced. The second embodiment is similar in design and function to the first embodiment described above and is designed essentially as shown in Figure 1 except for the following differences.

The measuring sensors of the second embodiment are attached to the wheels 16a-16d and are designated by the number 200 [and 200' – JPD] in Figures 11a and 11b, where they are shown in greater detail. Each measuring sensor 200, 200' is mounted in a tire and has a winding 202, [and 202', – JPD] which is essentially the same as the winding of the measuring sensor 14 of the first embodiment (Figure 1). The capacitors 204, [and 204', -- JPD] however, differ from the capacitors of the measuring sensors 14 in that their capacitance is a function of the tire pressure: $C = f(P)$, where C is the capacitance and P is the tire pressure.

The capacitor 204 shown in Figure 11A consists of very thin metal foil 206 with a dielectric 208. The dielectric 208 consists of an elastic material such as solid rubber, which can be reversibly deformed. After it has been deformed, therefore, the dielectric returns to its original shape.

The capacitor 204 has a first side 209, which, together with the coil 202, is vulcanized as previously described to the inside wall of the tire or mounted as previously mentioned on the rim. A second side 210 of the capacitor 204 is highly sensitive to the tire pressure. As the tire pressure increases, it compresses the capacitor 204, as a result of which the dielectric 208 is compressed. As a result of this compression, the capacitance of the capacitor 204 increases. Conversely, the capacitance of the capacitor 204 increases [Sic → decreases – JPD] when the

tire pressure drops again and the distance between the sides 209 and 210 of the capacitor increases.

Figure 11B shows an alternative design of the sensor 200' with a capacitor 204'. This is a thin-walled, cylindrical capacitor consisting of a cylindrical container 206' made of a strong dielectric such as Nylon, coated with a conductive film. One end 208' of the cylinder is sealed off hermetically from the air of the tire. The other end 210' of the cylinder is open to the air of the tire. The cylindrical container 206' is filled with a paste 212' or alternatively with a high-viscosity, nonconducting [Sic; conductive? – JPD] oil. Both are electrically conductive. When a conductive paste is used, it should have sufficient intermolecular forces or viscosity to prevent the paste from becoming distributed during the rotation of the wheel. The capacitor 204' has a first terminal 218', which is connected to the first end of the circuit, and a second terminal 216', which consists of a thin layer of conductive metal, deposited on the cylindrical surface of the container. It is connected to the second end of the circuit. The pressure of the tire enters through the opening 210' and is thus also present inside the cylinder. The compressive force exerted by the air 218' [Sic – JPD] in the cylinder 206' displaces the paste 216' [Sic → 212' – JPD], which changes the capacitance of the capacitor 204' correspondingly. The resonance frequency of the measuring sensor 200' thus depends on the pressure of the air in the tire.

Figures 12A and 12B show an electrical circuit diagram and a time series of the signals received by the receiver from the sensor 200 or 200'. The receiver 220 is mounted in the same way as the receiver 20 of Figure 1. When the tire rotates, the passive sensor 200 generates a disturbance in the electrical field between the coils 230 and 232 of the receiver 220, this disturbance being a function of tire pressure. The receiver 220 is permanently mounted on the wheel suspension at a point near the sensor 200, close to the tire flank 30. Each time the tire rotates and the sensor 200 passes by the coils, a train of square pulses with the resonance frequency of the LC circuit of the sensor 200 is generated. A time series of these pulses is shown at 232 [Sic → 233 – JPD] in Figure 12B. The duration of the individual pulse train tn1, tn2, tn3 depends on the speed of the vehicle.

Figure 12A shows a circuit diagram which illustrates the interaction between the measuring sensor and the receiver. The difference from the first embodiment is that a transistor 234, serving as a current switch, generates strong current pulses for the LED interface 80. The other components of the receiver 220 correspond to those of the previously described receiver 90.

As previously mentioned, the oscillation frequency of the output signal of the receiver 220 is the same as the resonance frequency of the sensor, which is shown schematically as curve 233 in Figure 12B.

Figure 13 shows the relationship between the oscillation period T of the signal at the output of the receiver 220 and the tire pressure at constant inductance of the coil 202 (compare Figures 11a, 11b). The curve is nonlinear when observed over a wide pressure range. Within a working range between 15 and 20 p.s.i., however, the curve is linear within a 5% tolerance. The linear approximation is indicated by the line 242 and shows the linear characteristic with which the curve 244 can be approximated.

Figure 15 [Sic → Figure 14 – JPD] shows a block circuit diagram of the entire system for detecting and displaying the current tire pressure of each tire according to the second embodiment. Only three sensors and three receivers are shown, but, of course, a four-wheel vehicle would have four sensors 200a-d and four receivers 220a-d. The sensors 200a-c are connected to corresponding receivers 220a-c. As a result of the rotation of the wheel, the recurrent coupling between the sensors 200 and the receivers 220 creates a pulse train, as illustrated in Figure 12B, at the output of the amplifier [Sic → receiver (see Figure 12a) – JPD] 220. The duration of the pulse period of the output signal at the output 230a of the first receiver 220a depends on the resonance frequency fp1 of the sensor 220a as follows: T1 = 1/fp1. The period of the pulses at the output 230b of the second receiver 220b depends on the resonance frequency fp2 of the circuit of the second sensor 220b as follows: t2 = 1/fp2. The same applies to the sensor 200c. The outputs 230a-c of the receivers 220 are connected to the inputs 232a-c of A/D converters 234a-c. The A/D converters 234a-c convert the duration of one or more periods into a serial data string, which can be read by a microprocessor 336 [Sic

236? – JPD]. This data string is stored in a memory component 238, until a new data string is produced by the next rotation of the same wheel and replaces the first. All of the converters operate in the same way. As a result, a value for the current tire pressure is stored at the output of each of the A/D converters 234a-c.

Figure 15 shows a function block diagram of the A/D converter 234a of Figure 14. This is described here by way of example. The A/D converter 234a has an input 240 and a detector input 242. A counter 244 and an amplifier are connected to the peak detector 246 at the detector input 242. Two signal inverters 248, 250 are connected to differentiating circuits 252 and 254. The output of differentiating circuit 252 is connected to an "enable" output of a memory register 280. When the last pulse train has been detected at the output of the inverter 248, the pulse trains are read from the output into the memory register 280. The output of the amplifier [Sic; differentiating circuit? – JPD] 254 is connected to the input of an RS trigger 256, which in turn resets the counter 244 when the next state occurs. A second counter 270 is connected both to the first counter 244 and to a quartz oscillator 274 and can open an input of the memory register 280 as desired, as will be explained below.

Figure 16 shows the time series of voltages which can be tapped at various nodes of the system. A pulse train with the duration t_n is sent to the A/D converter input 240. The time series of this signal at the input of the A/D converter 234 is shown at A in Figure 16 and is found at node A of Figure 15. The signals are sent to the input 242 of the detector 246 and to the clock input (C1) of the first counter 244. The input voltage at the detector is designated B in Figure 16, and the associated node is designated B in Figure 15. After the signals have been amplified by the peak detector 246 and shaped by the two inverters 248, 250, the leading edges of the pulses are differentiated by the differentiating circuits 252, 254. The output of the differentiating circuit 252 [Sic → 254 – JPD] is sent to the trigger 256, as a result of which this is set back to a logical "0". The output voltage of the trigger 256 is designated E in Figure 16, and the associated node is designated E in Figure 15. As soon as the output of the trigger becomes "0", the first counter 244 begins to count the pulses arriving from the amplifier 220a.

The voltage time series of the output registers 2^0, 2^1, 2^2, 2^3, 2^4 of the counter 244 are designated F in Figure 16, and the corresponding nodes are designated F in Figure 15. The 2^3-output of the first counter 244 is fed to the "enable" input of the second counter 230 [Sic → 270 – JPD]. Simultaneously, the leading edge of the pulse which was previously fed to the second input "R" of the counter 270 is differentiated by the RC circuit 272. The leading edge of the arriving pulse sets all of the output registers of the second counter 270 back to "0". Simultaneously, the input C1 of the second counter 270 is fed by the quartz oscillator 274, as a result of which the second counter 270 begins to count pulses. The counting of these pulses is shown at G in Figure 16, and the corresponding tap nodes are designated G in Figure 15. This counting continues until the "enable" input of the second counter 270 receives a logical "1". The second counter 270 stops counting as soon as a logical "0" is determined at its 2^3-output. Simultaneously with the determination of a logical "1" at the 2^4-output of the first counter 244, the RS trigger is reset; at this point, the output E becomes "0", and all outputs of the first counter 244 are set to "0". The number of pulses generated by the quartz oscillator 274 and counted by the second counter 270, represented in Figure 16 by the time series G, remains unchanged until a second pulse train arrives from the receiver 220a. This pulse train has the duration t_{n2}. At the end of the first pulse train from the amplifier 220, the trailing edge of the last pulse at the input to the detector 246a is differentiated by the differentiator 254. This pulse, shown in time series D in Figure 16 and tapped at point D in Figure 15, represents a write command for all of the output data of the counter 270 present in output register 280. The process described above begins again from the beginning when the second pulse train with the duration t_{n2} is detected at the input of the inverter.

As a result of this procedure, the inverter averages the duration of each of the pulse trains coming from the amplifier 220, such as the duration F of the 2^3-output of the first counter 244, which corresponds to 8 times the period of the input frequency of the amplifier 220a. The inverter then converts the time interval at the 2^3-output to a binary code N, which is proportional to the converted pulse duration. This binary code is stored in the output register 280. To increase the accuracy, the conversion can be carried out with a randomly selected time interval, which is a product of n pulses of the entered frequency. Thus accuracy can be

increased and deviations decreased either by increasing the duration of the formed time intervals or by increasing the frequency of the oscillator 274 used to measure the time interval.

As can be seen in Figure 14, the digital data from the outputs of the inverter are subjected to further processing by a microprocessor 236. The microprocessor 236 is connected by a data bus 232 [Sic → 282 – JPD], an address bus 284, and a control bus 286 to the programmable memory 238. The control bus 286 carries the control commands necessary for synchronization and flow direction control between the various parts of the circuit of Figure 14. Buffer amplifiers 288a-c are provided to improve the performance of the inverters. It can also be necessary to provide the control bus 286 with its own buffer amplifier (not shown). All buffer amplifiers should be equipped with outputs which can assume any one of three different states.

The memory unit 236 [Sic → 238 – JPD] can be programmed by the use of a write command key 290 and a delete command key 292. The two keys are close to a touch-sensitive display 294, which can display numbers between zero and nine, and which has a reset key (not shown) and a set key. The interface [i.e., 295? –JPD] can show the pressure of any tire, such 24 p.s.i. for the right front tire 16a. In the case of a truck, for example, it could show the pressure of the tire identified on a second display, here tire 16. The touch-sensitive display 294 of the interface [Sic; the interface 295 of the touch-sensitive display 294? – JPD] is connected to the data bus 282 and to the control bus 286 [Sic → address bus 284? -- JPD] by an analyzer 296 and a digital interface driver 298.

When a tire pressure monitoring system 10 according to the second embodiment is installed in a motor vehicle, the driver can initialize the tire pressure monitoring system in the following manner. First, each tire is pumped up to 50% of the prescribed pressure. Then the driver activates the display 294 by touching the number which corresponds to the number of the selected tire. Then he actuates the set key 290 to generate a write command. Next, the microprocessor 236 selects the suitable bus and enters the code arriving from the inverter into the memory 238. For example, the first entry A for the tire which has been pumped up to 50% of the desired pressure is assigned the value $N1_{(1/2)}$, as shown in Figure 17.

Then the tire is pumped up to the nominal pressure, and the new pressure value B is stored. The 50% value and the fully pumped value are determined for each tire on the vehicle, and these pressure values are stored in the memory unit. These are the values for 50% of the nominal pressure and for the nominal pressure. They are entered as $1/2P_{nom}$ and P_{nom}, corresponding to points A and B in Figure 17, to which the values $N1_{(1/2)}$ and $N1_{(1)}$ also correspond.

While the car is being driven and the tires are rotating, the microprocessor 236 operates in the following way. First, a clock pulse (not shown in Figure 14) generates a read command for the first A/D converter 234a. The code thus obtained is then written into the memory of the microprocessor 236. The microprocessor 236 compares the current code value with the code for $N1_{(1/2)}$. If the current code value is lower than this code, the microprocessor displays the corresponding tire number and the tire pressure. The tire pressure of the current tire (N1, N2, . . .) is obtained by linear extrapolation between the two known points A and B (see Figure 17). If the comparison shows that the current code value is above the code $N1_{(1/2)}$, no warning is shown on the display 294. The other tires are checked in the same way.

As soon as all the current tire pressures have been recorded after one rotation of each tire, the pressures are displayed continuously on the display unit 294. This is especially important when a tire with too little pressure represents a significant safety risk. Thus the driver can monitor the tire pressure continuously. For this purpose, he need only press the set key 290 on the touch-sensitive display, and the corresponding tire number and its tire pressure will be shown simultaneously.

The reset key is used to shift the display 294 into automatic monitoring mode. In this mode, the threshold values will be adjusted automatically by the microprocessor 236.

3rd Embodiment

Figures 22-30 describe a third embodiment, which makes it possible to monitor the tire pressures continuously and also to obtain a very accurate digital output of the tire pressure

measurements. This third embodiment resembles the first two, except that the selected sensor uses changes in inductance to generate the measurement signal instead of changes in capacitance, as in the case of the other two embodiments.

Figure 22 shows the basic design of the tire pressure monitoring system of the third embodiment. It is installed in the vehicle in the same way as in Figure 1 and has a passive sensor 346 [Sic → 356 – JPD] on the inner flank 358 of the tire 360. The sensor 356 consists of a resonance circuit 362 with a coil 364 and a capacitor 366 (see Figure 23) and of a pressure sensor 368. A receiver 370 is attached to the wheel suspension in such a way that that it remains at an essentially constant distance L from the sensor 356 or the line along which the sensor 356 travels. The distance L can be in the range of 0-18 cm. The pressure sensor 368 in the tire 360 converts changes in the tire pressure to changes in the inductance of the coil 364. Of course, the sensor 356 can also be attached to the rim 300 in the manner shown in Figures 18 and 20, for example, as will be explained further below.

Figure 23 illustrates the physical principle of this third embodiment. The receiver 370 has an amplifier 372, a first coil 374, and a second coil 376. The two coils enclose an angle α. This orientation of the coils 374, 376 brings about an electromagnetic coupling between them. They are formed by winding wire around relatively long coil carriers. A first row of windings is wound onto the entire length of the coil carrier, and following windings are wound on top of these first windings, again along the entire length. The desired coupling can also be achieved by adjusting the axial alignment of the essentially flat coils 374, 376 as shown in Figure 24. That is, the axial distance d, like the angle α in Figure 23, can be changed to adjust the inductive coupling between the coils 374 and 376. In the form shown in Figure 24, the coils 374, 376 are preferably designed in a manner similar to that shown in Figure 27 and 28, so that they have a spiral-like coil form instead of the long coil body of the coils shown in Figure 23.

The positions of the coils 374, 376 are adjusted by changing the angle α or the distance d in such a way that essentially no feedback or possibly negative feedback is obtained, as a result of which the receiver 370 "waits" in a non-oscillating rest state as long as the sensor 356 is not in working distance of the receiver 370. The frequency and amplitude of the oscillations

of the amplifier 372 depend in principle on its amplification factor, on the degree of feedback of the two coils 374, 476, and on the resonance frequency of the sensor 356. When the resonance circuit 362 with the coil 364 and the capacitor 366 is brought into working distance of the two coils 374, 376, a positive feedback develops and an "active" oscillation state is present, which depends on the coupling effect between the resonance circuit 362 and the two coils 374, 376, as illustrated in Figure 23.

Figure 25a shows a conductor loop 378 of the coil 374 and a conductor loop 380 of the coil 376 with the coupled currents 11 and 12 [Sic → I_1 and I_2 – JPD]. By arranging the conductor loops 374 and 376 differently in space as shown in Figure 25b, the currents 11 and 12 [Sic → I_1 and I_2 – JPD] can be made to flow in opposite directions. If they flow in the same direction, positive feedback is present at the amplifier 372. If they flow in opposite directions, negative feedback is present at the amplifier 372. This is expressed in the figures by $\beta > 0$ and $\beta < 1$.

The phase of the amplifier 372 is balanced when the degree and phase of the negative feedback are the same as those of the positive feedback. Positive (or negative) feedback can be achieved by back-coupling the output and the input of the amplifier 372 by means of a resistor. Negative (or positive) feedback through the coils 374, 376 can be compensated by choosing an appropriate resistance value. These coils can in turn be aligned at an angle α or at a distance d with respect to each to obtain feedback of the desired degree and the phase (see Figure 23 and 24). If the positive feedback through the resistor is greater than the negative feedback through the two coils 374, 376, the amplifier 372 is in the "active" oscillating state. If the negative feedback is equal to or greater than the positive feedback, the amplifier 372 is in the non-oscillating rest state, which is the preferred state for this embodiment. This means that the feedback can be made either positive or negative through the choice of the resistance value in the feedback branch. Once the coils 374 and 376 have been suitably aligned, any further adjustment to the resistance affects essentially only the sensitivity to distortion. The sensitivity of the amplifier 372 is determined by the feedback resistance, which determines how strongly the phase is shifted in the positive or negative direction. The alignment of the coils 374, 376,

however, determines the direction in which the phase is shifted in the case of positive or negative feedback.

To fine-tune the coupling between the two coils 374, 376, a thin metal strip 382 can be used, as shown in Figure 23 and as previously described on the basis of Figure 6. By changing the position of the metal strip 382, the interaction between the electromagnetic fields of the two coils 374, 376 can be changed, so that a stronger or a weaker coupling between the coils 374, 376 is obtained. This metal strip 382 is therefore used to increase or to decrease the electromagnetic coupling effect between the coils 374, 376 and thus to balance the amplifier 370 during or after production. The same procedure can also be used to adjust the sensitivity of the amplifier 320 [Sic; receiver 370? – JPD] to the sensor 362 when the sensor is in working distance of the receiver 370. If the amplifier 372 is in the rest state, that is, if its positive feedback is being compensated by the induced negative feedback, and if the resonance circuit 362 is in working distance of the receiver and has been adjusted to the natural frequency of the amplifier, the resonance circuit can shift the phase equilibrium of the amplifier 372 and generate an oscillation, the amplitude and frequency of which depend on the overall impedance of the resonance circuit 362. This means that a pressure capsule 368 which converts changes in pressure to changes in the inductance of the resonance circuit 364 can be used to change the phase equilibrium of the receiver 370 and thus to transmit the change in inductance.

This approach is summarized in the block circuit diagram of Figure 26. The sensor 356 converts the pressure P. For this purpose, the pressure P (block 382) is converted by the pressure capsule 368 into a change in the inductance L of the coil 364 (block 384). As a result, the resonance frequency F of the resonance oscillator 362 is changed (block 386). This changed resonance frequency influences the phase of the feedback between the two coils 374, 376 of the receiver 370, which is located at distance L. As a result, the oscillation state of the amplifier 372 is changed, which can be measured and correlated with the current pressure.

Figures 27A and 27B show the passive sensor 356 of the third embodiment in greater detail. This sensor, too, requires no outside energy supply. It consists of a solid insulating base 388 with a conductive surface 390. A thin metal spring-like or elastic membrane 392 is soldered or glued to the base 388, so that a hermetically sealed air chamber 394 is formed, in

which the air is at ambient pressure. A small, rectangular piece of ferrite 396 of high permeability is attached to the inside surface of the membrane. A ferrite horseshoe magnet 398, furthermore, is attached to the base 388 and is also sealed off against the air chamber 394. A flat coil 346 [Sic → 364 – JPD] with four windings with a diameter of 3.5-5.5 cm is attached to the outside surface of the base 388 and passes between the base 388 and the horseshoe magnet 398. As shown in Figure 27 [Sic → 27B – JPD], a capacitor 366 is connected to the coil 364. Thus the coil 364 is provided with a ferromagnetic core, which is formed by the two ferrite parts 396, 398. The gap G between them is variable, depending on the pressure P acting on the membrane 392. When the pressure P on the sensor 356 changes, the membrane 392, as shown in Figure 27 [Sic → 27A – JPD], is pushed downward, as a result of which the gap G narrows. The sensor 356 is highly sensitive to even slight changes in the gap G. Variations on the order of a few μm can change the inductance L of the coil 342 by 300-900%. The pressure transducer is preferably adjusted in such a way that the change in the gap G is between 0 and 500 μm. The pronounced change in the inductance is the result of the high permeability of the ferrite components 396 and 398, which is on the order of approximately 10,000.

Figures 28A and 28B show a modification of the sensor 356, designated here 356'. The difference is that two ferrite horseshoes 400 and 402 surround the coil 364. A pressure-sensitive rubber foam material 404 containing many microcavities is placed in the gap G between the two ferrite parts 400, 402. The microcavities contain air under normal pressure. When an external pressure P is exerted, the material 404 is compressed, as a result of which the gap G between the ferrite parts 400 and 402 changes. Here again, a small change in the gap G results in a large change in the inductance L of the coil 364.

In sensor of the type illustrated in Figures 27 and 28, the inductance of the flat coil 334 changes as described by the following equation:

$$L = (w^2 mi)/R_b \qquad (1),$$

where w stands for the number of windings of the flat coil 364, mi for the length of coil covered by the ferromagnetic core, and R_b for the magnetic resistance of the air gap G. The latter can be expressed by the following equation:

$$R_b = 80{,}000{,}000\ G/(S_2\ \mu_o) \qquad (2),$$

where S_2 is the cross section of the ferrite core, and μ_o is its permeability.

By combining Equations (1) and (2), we obtain the following for the inductance L:

$$L = w^2 mi\ S_2\mu_o/(80{,}000{,}000\ G) \qquad (3).$$

This formula shows that even very small changes in the width of the gap G produce large changes in the inductance L. When this is combined with the known equation for the resonance frequency of an oscillating circuit 362, we obtain the following relationship between the resonance frequency and the change in the gap:

$$F = 1/(2\pi\sqrt{LC}) = 1/(2\ \pi\sqrt{w^2 mi\ S_2\mu_o/(80{,}000{,}000\ G)} \qquad (4).$$

Figure 29 shows the receiver 370 together with the digital display interface 406, and Figure 30 shows the corresponding time series. The receiver 370 has a two-stage amplifier 372 with a first op amp 408 and a second op amp 410. The resistors R1, R2, R3, and R4 determine the amplification and the feedback sensitivity of the two amplifier stages. They form the feedback branch. A coil L1 and a capacitor C1 form an input resonance circuit. A coil L2 is connected by a current-amplifying transistor T1 to the output of the second op amp 410. Resistors R5 and R6 adjust the direct-current level through the op amps 408 and 410 and function as voltage dividers. Resistors R7 and R10 [Sic → R8 – JPD] work together with the capacitor C2 to adjust the mode and to bias the voltage for the transistor T1.

When the sensor 346 with the pressure-sensitive ferrite core passes through or into the electromagnetic field of the two coils L1 and L2 of the receiver 370, the curve designated A is

obtained at node A. These are square-wave oscillations. The oscillation frequency depends on the measured pressure; the duration of the oscillations depends on the rotational speed of the tire. These square-wave oscillations are sent to the digital display interface 406, which converts the analog measurements into digital values. For this purpose, the square-wave oscillations are first sent to a pulse shaper 412. This is a function generator with adjustable frequency and pulse duty factor. It is also supplied with the output of a pulse detector 414. The pulse shaper 412 shapes the digital pulses, which are then counted by a counter 416, which is timed by a quartz oscillator 418 via a pulse shaper 420. The wave train transmitted by the pulse detector 414 is shown as time series B in Figure 30. A switch 322 [Sic → 422 – JPD] turns the pulse shaper 412 on.

A programmable memory 424 stores a table of the relationship between the frequency and the digital value of the measured pressure. The square-wave train designated C in Figure 30 is present at the output 426 of the pulse shaper 412; this wave train has the width of one period of the wave train, shown in A, present at the output of the receiver 370. On the basis of this wave train, the counter 416 can reliably count out the frequency, as shown in wave train D of Figure 30. Two additional pulses are generated at the output 426 coincident with or after the trailing edge. First the pulse designated E in Figure 30 is generated at the output 426 of the pulse shaper 412, and then the pulse designated F in Figure 30 [at the bottom of the figure, incorrectly labeled "E". – JPD] is generated at the output 430. The first pulse resets the counter 416, and the second pulse actuates a trigger 432, so that the number counted by the counter 416 can be compared with a number stored in the memory 442 [Sic; 434? – JPD] of the microprocessor 436. The result of this comparison is converted by the programmable memory 424 into a signal, which an LCD driver 428 [Sic → 438 – JPD] displays on the display unit 440 as a digital readout of the measured pressure.

In this third embodiment of the tire pressure monitoring system 354, the pressure in the tire is accurately detected by the sensor 356, where, thanks to the ferrite core, the inductance L of the sensor's coil 354 varies with the pressure. The receiver 370 preferably starts out in a non-oscillating rest state, in which the orientation of the coils 374, 376 of the receiver 370 to each other produces negative feedback between the input and the output of the amplifier 372.

As soon as the sensor 356 is brought into working distance of the receiver 370, however, the receiver is activated, the resulting oscillations being a function of the resonance frequency of the resonance circuit 362. Because this frequency is pressure-dependent, the oscillation frequency of the amplifier 372 can be detected and used as a measure of the tire pressure.

Figure 18 shows how the sensor 14a of the first embodiment is attached to the rim 300 of the tire 16a. The sensor 14a has a first housing 302 and a second housing 304, which are connected electrically to each other by a conductor 306 and the rim 300. The first housing 302 contains the circuit 32 with the coil 34, and the second housing 304 contains the capacitor 36 and the switching element 38 (see also Figure 21).

The switching element 38, which is shown in greater detail in Figure 21, is installed in the housing 304. It has a cover 308 of glass fiber-reinforced plastic and a base 310 of glass fiber- reinforced plastic. Between the cover 308 and the bottom part 310 there is a switching contact or pressure capsule 312, which is formed out of two conductive or flexible disks 314, which are designated by reference number 42 in Figure 2. The pressure capsule 312, which is formed by these two disks 314, is hermetically sealed, so that a sealed air cavity 316 is present inside. The pressure capsule 312 is in electrical contact with the rim 300, as can be seen in Figure 18, by way of a conductive fastener 318, which is soldered to the rim 300, and by a first foil conductor 320. The pressure capsule 312, furthermore, is contacted electrically by a second conductor 322, which is fastened to the bottom surface of the cover 308. The cover 308 and the bottom part 312 [Sic → base 310 – JPD] are kept apart by a ring-shaped insulator 323, so that the chamber 316 of the pressure transducer 312 can expand or contract, as a result of which the circuit 32 shown in Figure 2 is opened or closed. As soon as the tire pressure falls below a predetermined value, the pressure capsule 312 establishes a connection between the conductor 320 and the conductor 322 via the conductive fastener 318. The first [Sic → second – JPD] housing 304 also has a capacitor 36, attached to the top surface, which is connected to the conductor 322 and is in parallel with the coil in the first housing 302.

As can be seen in Figures 18 and 19, the sensor 14a, accommodated in the first housing 302 and in the second housing 304, is attached to the rim of the wheel. The figures show two possible fastening methods. In both, the second housing 304 is fastened to the inner part [of

the outside circumference – JPD] of the rim 300 by means of a suitable adhesive. To secure the housing 304 additionally on the rim 300, an adjustable metal band 324 is wrapped around the inner part of the rim 300 so that it presses down on the O-ring 326, which rests on top of the housing 304. The metal band 324 passes over the O-ring 326 in such a way that there is sufficient room for the pressure transducer 312 to expand. Alternatively, an elastic Nylon belt or some other suitable fastening mechanism can be used in place of the adjustable metal band 324.

In the case of the first fastening technique shown in Figure 18, the conductive fastener 318 is soldered directly to the rim 300. This forms the first section of the conductor. The second conductor 322 proceeds from the bottom surface of the cover 308 to the capacitor 336 [Sic → 36 – JPD]. The capacitor is connected to the conductive foil 306, which is isolated from the rim 300 and which passes transversely across the flange 328 of the rim 300. The conductive foil 306 passes over the flange 328 and is then fastened to the polyethylene body 330 of the housing 303 [Sic → 302 – JPD] by means of a screw 332. One of the terminals of the coil 34 is also connected electrically to the foil 306 by means of the screw 332. The other terminal of the coil 34 is connected to the flange 328 of the rim 300 by a second fastening screw 334 and to a second strip of foil 336, which is in electrical contact with the flange 328. The coil 34 has approximately 230 windings, which are enclosed by the polyethylene body 330, shown cut away in Figure 18. The body is fastened to the flange 328 of the rim 330 by two metal straps 338. These straps are riveted to the polyethylene body 330 of the first housing 302. The metal straps 338 are elastic enough that they can clamp themselves onto the flange 328 of the rim 300. The coil 34 is thus fastened directly to the outside surface of the rim 300. The receiver 20a can then be installed on the chassis or on the wheel suspension close to the coil 34 in such a way that the coil 34 is on a plane which is essentially parallel to the plane of the coils 62, 64 of the receiver 20a.

Figure 19 shows a second technique for fastening the sensor 14a to the rim 300. Elements or components which are similar to the fastening technique of Figure 18 carry the same reference numbers and are not explained here again. In this second fastening technique, the rim 300 is not used as a conductor. This can be advantageous in cases where the rim is

made of aluminum, for example, with which it is difficult to make electrical contact. Instead of that, a second piece of conductive foil 342 is used, which is also insulated from the rim 300. The conductor 322 of the switching element 38 is connected electrically to the foil 306, whereas the conductor 320 of the switching element 38 is connected to the foil 342. These foil conductors 306, 342 are guided over the flange 328 of the rim 300 and continue to be isolated from the rim 300. The contacts of the foil conductors 306, 334 [Sic → 342 – JPD] are contacted by elastic conductive clamps 338, which are riveted to the housing 302 and connected to the terminals of the coil 34 to close the circuit. When this second fastening technique is used, the tire 16a can be mounted on the rim 300 before the first housing 302 of the sensor 14a has been attached to the edge 328 of the rim 300. After the tire 16a has been pulled onto the rim 300, the first housing 302 of the sensor 14a can simply be clipped onto the exposed contact surfaces of the foils 302, 342, in a manner similar to that in which a normal balancing weight is clipped onto the flange of the rim. For this purpose, of course, it is essential that electrical contact can be made with the surfaces of the conductive foils 306, 342 in the area of the rim flange, and that the bottom surfaces of the conductive foils 302, 342 are isolated from the rim 300. The bottom surfaces of the straps 338 can then establish contact with these conductive sections of the foil conductors 306, 342 when the first housing 302 is attached to the flange of the rim.

Figure 20 shows a third fastening technique for fastening the measuring sensor 14a to the rim 300. Here, too, elements which are similar to those of the first two fastening techniques have been given the same reference numbers and are not explained again. In this design, the coil 34 is attached essentially at a right angle to the bed of the rim by means of a flexible fastening mechanism 344. For example, the first housing 302 can be made of a plastic adhesive, which encapsulates the entire coil 34. As a result, the coil 34 can be positioned in a plane which is essentially parallel to the plane of the coils 62, 64 of the receiver 20a. The switching element 38 is installed in the housing 304 and mounted on the rim 300 near the coil 34. This housing 304 is attached to the rim 300 preferably in the same way as that shown in Figures 18 and 19, so that two foil conductors 346, 348 establish the necessary electrical contact between the coil 34 and the housing 304 to form the circuit 32. When this fastening technique is used, the center axis 350 of the coil 34 must be above the flange 328 of the rim

300, so that there is enough overlap 352 to ensure good electromagnetic coupling with the receiver 20a. In addition, the coil 34 is close to the receiver 20, being about 0-18 cm away from it.

By the use of one or the other of the three fastening techniques described above and as illustrated in Figures 18-20, the sensor 14a can be easily attached in a suitable position with respect to the receiver 20a without the need to modify the tire 16a by making a hole in it, for example, to allow the sensor 14a to be mounted in the flank of the tire 16a. As a result, any tire can be mounted on the rim 300, because the rim 300 is already designed in such a way that the sensor 14a can be fastened to it as shown in Figures 18 and 20. This rim 300 is a standard rim and does not have to be modified in any other way except to attach the housings 302, 304 of the sensor 14a to it as shown.

Claims

1. Tire pressure monitoring system for at least one tire (16) of a vehicle:

– with a sensor (14, 200, 200', 356), which is in a fixed position relative to the tire (16) and which detects the pressure of this tire (16);

– with a receiver (20, 90, 220, 370),

• which is mounted outside the tire (16) but close to the sensor (14, 200, 200', 356) in a fixed position relative to the vehicle to generate a signal indicating the tire pressure detected by the sensor (14, 200, 200' 356); and

• which has a first coil (62, 230, 374), a second coil (64, 232, 376), and an amplifier (70, 94, 372) with a feedback branch;

• where the first and the second coils (62, 230, 374; 64, 232, 376) are arranged with respect to each other in such a way that, after electromagnetic coupling has been established between them, the feedback in the feedback branch is either zero or negative; and

– with a tire pressure display unit (80), which is connected to the receiver (20, 90, 220, 370) and displays the tire pressure on the basis of the signals it receives.

2. Tire pressure monitoring system according to Claim 1, characterized in that the sensor (14, 200, 200', 356) has an LC circuit (32, 362) with a coil (34, 202, 364) and a capacitor (36, 204, 366).

3. Tire pressure monitoring system according to Claim 2, characterized in that the passive LC circuit (32, 362) is conductive when the tire pressure is outside a predetermined range and is nonconductive when the tire pressure is within the predetermined range.

4. Tire pressure monitoring system according to Claim 2 or Claim 3, characterized in that the inductance L of the coil (364) of the passive LC circuit (362) is a function of the tire pressure.

5. Tire pressure monitoring system according to one of the preceding claims, characterized in that the measuring sensor (14, 200, 200', 356) is accommodated in a first housing (302) and in a second housing (304), which are attached to the rim (300) of the tire (16).

6. Tire pressure monitoring system according to Claim 5, characterized in that the first housing (302) is attached to an edge (328) of the rim (300), whereas the second housing (304) is attached to the rim (300) at a point inside the tire (16).

7. Monitoring system for a first parameter,

– with a measuring sensor (14, 200, 200', 356) mounted at a first location (16) to detect the first parameter;

– with a receiver (20, 90, 220, 370),

• which is in a second location a certain distance away from first location (16) but close to the sensor (14, 200, 200', 356) to generate a signal indicating the first parameter; and

• which has a first coil (62, 230, 374), a second coil (64, 232, 374 [Sic → 376 – JPD]), and an amplifier (70, 94, 372) with a feedback branch;

• where the first and the second coils (62, 230, 374; 64, 232, 376) are arranged with respect to each other in such a way that, after electromagnetic coupling has been established between them, the feedback in the feedback branch is either zero or negative; and

– with a display unit (80), which is connected to the receiver (20, 90, 220, 370) and displays the first parameter to the user.

8. Monitoring system according to Claim 7, characterized in that the sensor (14, 200, 200', 356) is in a fixed position relative to a tire (16) of a vehicle and the receiver (20, 90, 220, 370) is in a fixed position relative to the vehicle, as a result of which the sensor (14, 200, 200', 356) is able to detect the tire pressure.

9. Monitoring system according to Claim 7 or Claim 8, characterized in that the sensor (14, 200, 200', 356) has an LC circuit (32, 362) with a coil (34, 202, 364) and a capacitor (36, 204, 366), and in that the passive LC circuit (32, 362) is conductive when the first parameter is outside a predetermined range and is nonconductive when the first parameter is within the predetermined range

10. Monitoring system according to one of Claims 7 with 9, characterized in that the sensor (356) has an LC circuit (362) with a coil (364) and a capacitor (366), where the inductance L of the coil (364) is a function of the first parameter.

11. Monitoring system according to one of Claims 7 with 10 in conjunction with Claim 8, characterized in that the measuring sensor (14, 200, 200', 356) is accommodated in a first housing (302) and in a second housing (304), which are attached to the rim (300) of the tire (16).

12. Monitoring system according to one of Claims 7 with 11, characterized in that the feedback in the feedback branch is positive when the sensor (14, 200, 200', 356) is in working distance of, and electromagnetically coupled with, the receiver (20, 90, 220, 370).

13. Tire pressure monitoring system for at least one tire (16) mounted on a wheel rim (300) of a vehicle

– with a sensor (14, 200, 200', 356) accommodated in a first housing (302) and in a second housing (304), where the first housing (302) and the second housing (304) are attached to the wheel rim (300) and electrically connected to each other;

– with a receiver (20, 90, 220, 370),

• which is mounted outside the tire (16) but close to the sensor (14, 200, 200', 356) in a fixed position relative to the vehicle; and

• which can be electromagnetically coupled with the sensor (14, 200, 200' 356) to generate a signal indicating the tire pressure detected by the sensor (14, 200, 200' 356); and

– with a tire pressure display (80), which is connected to the receiver (20, 90, 220, 370) and which displays the tire pressure on the basis of the signals it receives.

14. Tire pressure monitoring system according to Claim 13, characterized in that the first housing (302) is attached to an edge (328) of the rim (300), and the second housing (304) is attached to the rim at a point inside the tire (16).

15. Tire pressure monitoring system according to Claim 13 or 14, characterized in that the first housing (302) contains a coil (34, 202, 364), and the second housing (304) contains a pressure capsule.

16. Tire pressure monitoring system according to Claim 15, characterized in that the coil (34, 202, 364) is attached to the rim (300) in a first plane, which is essentially parallel to a second plane, on which lie a first coil (62, 320, 374) and a second coil (64, 232, 376), which are built into the receiver (20, 90, 220, 370).

17. Tire pressure monitoring system according to one of Claims 13 with 16, characterized in that the second housing (304) is attached to the rim (300) by means of an adjustable metal band (324), which is extends over an O-ring (326) surrounding the second housing (304) and is wrapped around the rim (300).

18. Tire pressure monitoring system according to one of Claims 13 with 17, characterized in that the second housing (304) is attached to the rim (300) by means of an adhesive (344).

19. Tire pressure monitoring system according to one Claims 13 with 18 in conjunction with Claim 15, characterized in that the coil (34, 302, 364) in the first housing (302) is essentially perpendicular to the rim (300), where the center axis of the coil (34, 202, 364) is positioned above the edge (328) of the rim.

20. Monitoring system for a first parameter

– with a sensor (356) in a first location (16), the sensor being equipped with a coil (364) with an inductance L which is aligned with a ferrite core (398, 396, 400, 402), which changes the inductance L of the coil (364), so that the sensor (356) is able to detect the first parameter, and

– with a receiver (370), which is in a second location a certain distance away from the first location (16) but close to the sensor (356) and which can be electromagnetically coupled with the sensor (356) to generate a signal indicating the first parameter detected by the sensor (356).

21. Monitoring system according to Claim 20, characterized in that the sensor (356) is in a fixed position relative to the tire (16) of a vehicle, and the receiver (370) is in a fixed position relative to the vehicle, as a result of which the sensor (356) is able to detect the tire pressure of the tire (16).

22. Monitoring system according to Claim 20 or Claim 21, characterized in that the feedback in a feedback branch of the receiver (370) is positive when the sensor (356) is in working distance of, and electromagnetically coupled with, the receiver (370).

23. Monitoring system according to Claim 20, characterized in that the receiver (370) has a first coil (374), a second coil (376), and an amplifier (372) with the feedback branch, where the first and second coils (374, 376) are oriented with respect to each other in such a way that, after electromagnetic coupling has been established between them, the feedback in the feedback branch is either zero or negative.

24. Monitoring system according to one of Claims 20 with 23, characterized in that the ferrite core has a second ferrite part (398, 402) and a first ferrite part (396, 400), which is oriented with respect to the second ferrite part (398, 400) in such a way that a variable gap (G) is created, where a change in the gap (G) changes the inductance L of the coil (364).

25. Monitoring system according to Claim 24, characterized in that the gap (G) contains a material (404) which expands or contracts upon variation of the first parameter.

26. Monitoring system according to Claim 24, characterized in that the first ferrite part (396, 400) and the second ferrite part (398, 402) of the ferrite core are mounted with respect to a flexible membrane (392) in such a way that a displacement of the flexible membrane (392) caused by a change in the first parameter changes the gap (G).

27. Monitoring system for a first parameter:

– with a sensor (14, 200, 200', 356) mounted at a first location (16) to detect the first parameter;

– with a receiver (20, 90, 220, 370),

• which is at a second location a certain distance away from first location (16) but close to the sensor (14) to generate a signal indicating the first parameter; and

• which has an amplifier (70, 94, 372) with a feedback branch, which is in a non-oscillating rest state when the sensor (14, 200, 200', 356) is not electromagnetically coupled with the receiver (20, 90, 220, 370) and an active, oscillating state when the sensor (14, 200, 200', 356) is electromagnetically coupled with the receiver (20, 90, 220, 370)

28. Monitoring system according to Claim 27, characterized in that the sensor (14, 200, 200', 356) has an LC circuit (32, 362) with a coil (34, 202, 364) and a capacitor (36, 204, 366).

29. Monitoring system according to Claim 28, characterized in that the passive LC circuit (32, 362) is conductive when the first parameter is outside a predetermined range and is nonconductive when the first parameter is within the predetermined range.

30. Monitoring system according to one of Claims 27 with 29 characterized in that the sensor (14, 200, 200', 356) is electromagnetically coupled with the receiver (20, 90, 220, 370) when the LC circuit (32, 362) of the sensor (14, 200, 200', 356) is conductive and the sensor (14, 200, 200', 356) is in working distance of the receiver (20, 90, 220, 370).

31. Monitoring system according to one of Claims 27 with 30, characterized in that the sensor (356) has a coil (364), the inductance of which depends on the first parameter.

32. Sensor (356) for a first parameter

– with a capacitor (366);

– with a coil (364) with an inductance L; and

– with a ferrite core (396, 398, 400, 402), aligned with the coil (364);

– where the dependence of the inductance L on the first parameter is established by the movement of the ferrite core (396, 398, 400, 402) relative to the coil (364).

33. Sensor according to Claim 32, characterized in that the ferrite core has a first ferrite part (396, 400) and a second ferrite part (398, 402), which are arranged with respect to each other in such a way that a gap (G) is formed, which depends on the first parameter.

34. Sensor according to Claim 33, characterized in that the first ferrite part (396) is essentially a rectangular block and the second ferrite part (398) is essentially U-shaped.

35. Sensor according to Claim 33, characterized in that both the first and the second ferrite parts (400, 402) are U-shaped.

36. Sensor according to Claim 32 with Claim 35, characterized in that the coil (364) has several windings, where each successive winding surrounds the preceding one so that a flat, spiral-like coil is formed.

37. Sensor according to one of Claims 32 with 36 in conjunction with Claim 33, characterized in that the coil (364) passes between the first ferrite part (396, 400) and the second ferrite part (398, 402).

38. Sensor according to one of Claims 32 with 37 in conjunction with Claim 33, characterized in that the gap (G) contains a material (404) which expands or contracts upon variation of the first parameter.

39. Sensor according to one of Claims 32 with 38 in conjunction with Claim 33, characterized in that the first ferrite part (396, 400) or the second ferrite part (398, 402) of the ferrite core is mounted with respect to or on a flexible membrane (392) in such a way that a displacement of the flexible membrane (392) caused by a change in the first parameter changes the gap (G).

40. Receiver for monitoring a first parameter by means of a sensor (14)

– with an amplifier (70, 94, 372) with a feedback branch;

– with a first coil (62, 230, 374) and a second coil (64, 232, 376) connected to the amplifier;

– where the amplifier (70, 94, 372) is in a non-oscillating rest state when the sensor (14, 200, 200', 356') is not electromagnetically coupled with the receiver (20, 90, 220, 370) and is in an active, oscillating state when the sensor (14, 200, 200', 356) is electromagnetically coupled with the receiver (20, 90, 220, 370).

41. Receiver according to Claim 40, characterized in that the amplifier (70, 94, 372) is a two-stage amplifier with a first operational amplifier (408) and a second operational amplifier (410).

42. Receiver according to Claim 40 or Claim 41, characterized in that the first coil (62, 230, 374) is connected to the input of the amplifier (70, 94, 372), the second coil (64, 232, 376) to its output.

43. Receiver according to one of Claims 40 with 42, characterized in that the first coil (62, 230, 374) and the second coil (64, 232, 376) are arranged with respect to each other in such a way that that, after electromagnetic coupling has been established between them, the feedback in the feedback branch is either zero or negative when the sensor (14, 200, 200', 356) is not electromagnetically coupled with the receiver (20, 90, 200, 370).

44. Receiver according to Claim 43, characterized in that the feedback in the feedback branch is either zero or negative, when the amplifier (70, 94, 372) is in the non-oscillating rest state and positive when the amplifier (70, 94, 372) is in the active oscillating state.

45. Receiver according to one of Claims 40 with 44, characterized in that the feedback branch is formed by several resistors installed between the input and the output of the amplifier (70, 94, 372).

17 pages of drawings attached.